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Depositional Environments and Sequence Stratigraphic Study of the "B1" Reservoir Sand, Well-16, Boga Field, Niger Delta, Nigeria

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ABSTRACT
The "B1" reservoir sand, in Boga field, Niger Delta, was investigated for the depositional environments and sequence stratigraphy. The study revealed eight lithofacies types. The lithofacies were integrated with the well log data from base to top of reservoir sandbodies into facies association that occur together and are considered to be genetically or environmentally related. Two facies' associations of the barrier bar shoreface succession, comprising the three main domains of Upper Shoreface, Middle Shoreface, Lower Shoreface and Shelf Mudstone subfacies and the Fluvial Channel-Point Bar. The facies association of the sand bodies in the study interval can be interpreted as a deposit of a prograding wave -dominated shoreface setting. The integration of wireline log and core data reveal that the environment of deposition of "B1" reservoir sands lies within the marginal marine environments. The well log sequence stratigraphic study of the cored interval, revealed one sequence, comprising of the Transgressive System Tract (TST) and Highstand System Tracts (HST). The Lowstand System Tracts (TST) shown on the wireline log was however not cored.
Keywords: Lithofacies, Depositional environment, Shoreface, Fluvial, Prograding, Sequence, System Tracts.

1.1 INTRODUCTION

Niger delta is a matured basin; several works have been undertaken on the Tertiary Niger delta sedimentary basin. Short and Stauble (1967) was one of the pioneer workers on the geology of the Niger delta. They provided the initial information on the sediments and subsurface distribution of the stratigraphic units in the Niger delta. In that work, Short and Stauble, (1967) studied the outline of the Niger delta and suggested that the major source rocks were shales of the Agbada Formation. Some works have also been done by Whitaker (1985); he identified the following environments in the Niger delta, mangrove swamp, channel deposits, shoreface and marine. This study is designed to take a critical look at the stratigraphy, and lithological characterization, in order to determine the various depositional environments and the sequence stratigraphic framework in the reservoir depth for the "B1" reservoir sand in Well-16, Boga Field based on sedimentological studies using core and log data.

1.2 Location of Study area

The study area, "B1" Reservoir Sand, Well-16, Boga Field, Niger Delta is located within the Greater Ughelli Depobelt of the Niger Delta region. It lies between longitude 5.05°E and 7.35°E and latitude 4.15°N and 6.01°N (figures 1) on the onshore part of the Niger Delta. The "B1" Reservoir Sand is between 3322m-3340.5m depth (18.5m thick).

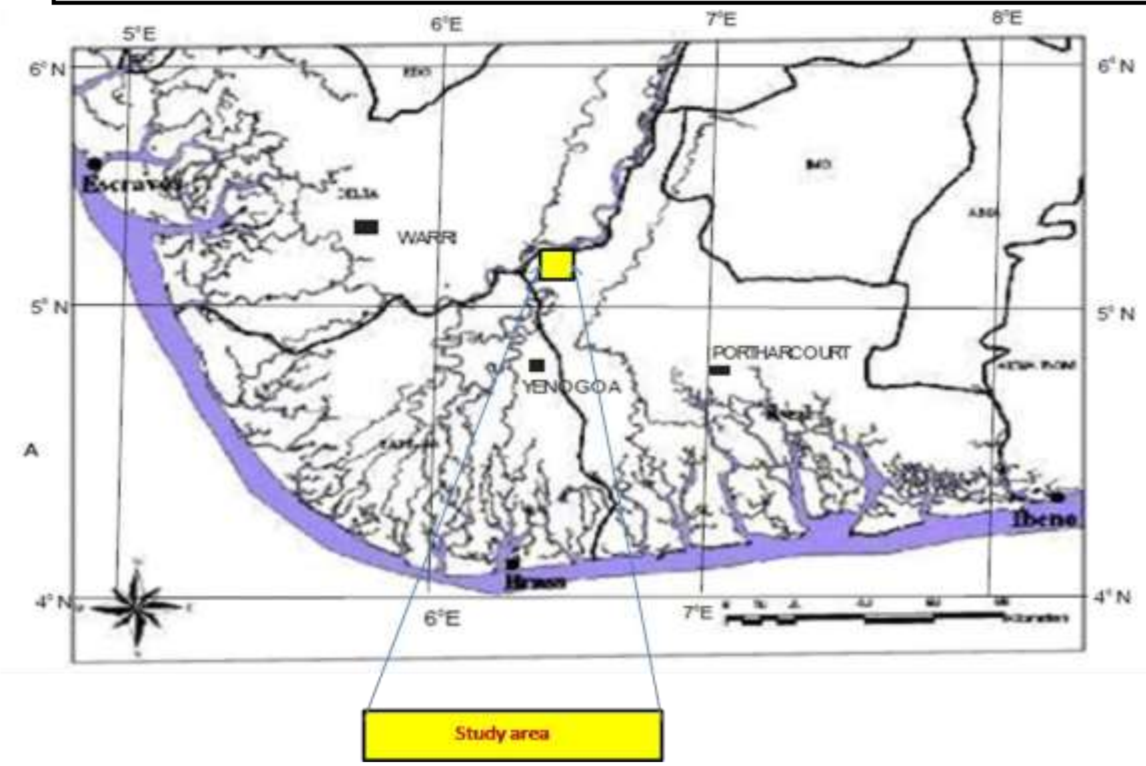


Figure 1-- Map of Niger Delta basin, showing location of study well

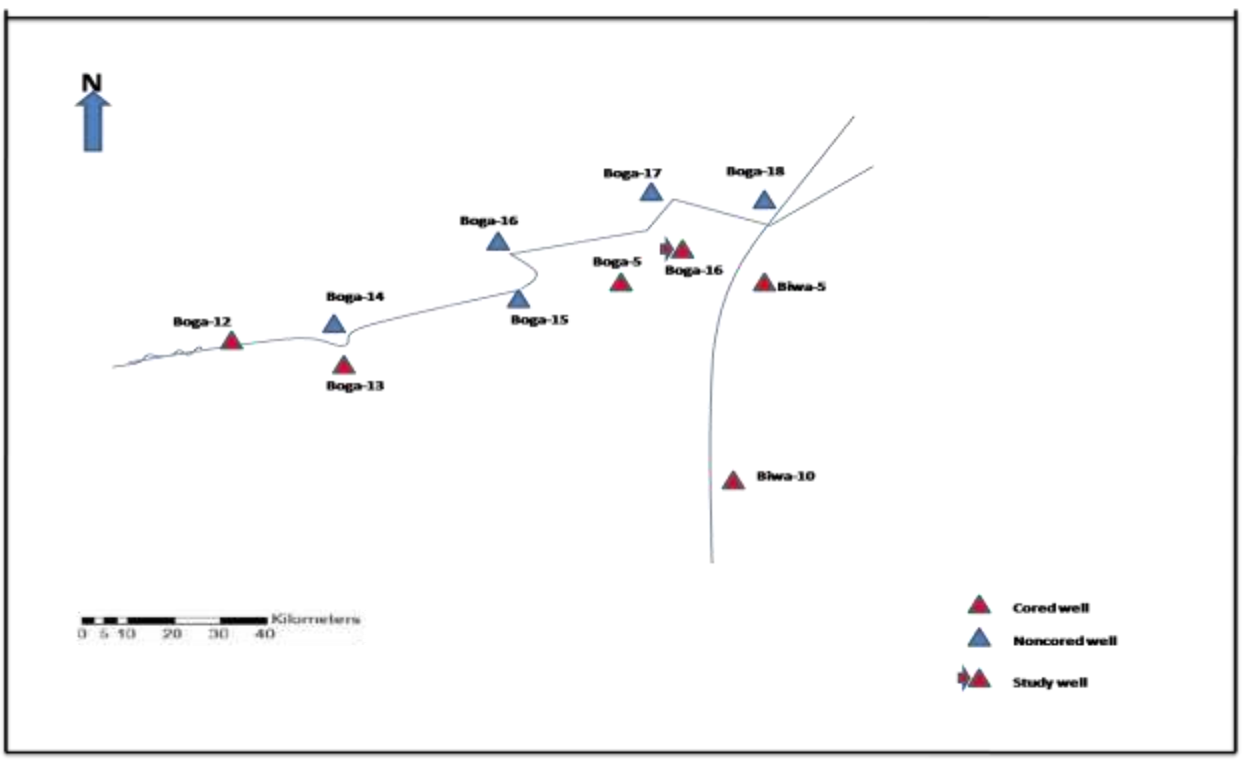


Figure 2: Map of Study Area (basemap) showing cored and noncored wells

1.3. Stratigraphic and Geologic Setting

Studies in the Niger Delta revealed three vertical lithostratigraphic subdivisions: the Benin Formation which is an upper delta top lithofacies; the Agbada Formation which contains the hydrocarbon reservoirs and the lower part; the Akata Formation, which is the over pressured shales and the source ofhydrocarbon generation. The type section as described by Short and Stauble (1967) is summarized below (table 1).

1.3.1 Benin Formation

The Benin formation which is the upper deltaic-top like lithofacies has been described as "coastal plain sands", the thickness of the Benin Formation ranges from 0-6000ft and is the source of the water supply. The formation outcrops in Benin, Onitsha and Owerri provinces and elsewhere in the delta area(Reyment, 1965). It consists mainly of massive, highly porous, fresh water sandstone with minor shale. The Benin formation extends from the west across the Niger Delta area and southwards beyond the present coastline. The sands and sandstone are coarse to fine and the sediment consist of alluvial and upper coastal plain sands that are up to 2000 m thick (Avbovbo, 1978)

Table 1: Regional stratigraphy of the Niger delta area (modified after Short and Stauble, 1967).

SUBSURFACE			SURFACE OUTCROPS		
YOUNGEST KNOWN AGE	FORMATION	OLDEST KNOWN AGE	YOUNGEST KNOWN AGE	FORMATION	OLDEST KNOWN AGE
RECENT	BENIN	OLIGOCENE	PLIO/ PLEISTOCENE	BENIN	MIOCENE
RECENT	AGBADA	EOCENE	MIOCENE	OGWASHI-ASABA	OLIGOCENE
			EOCENE	AMEKI	EOCENE
RECENT	AKATA	EOCENE	L. EOCENE	IMO SHALE	PALEOCENE
			PALEOCENE	NSUKKA	MAESTRICHTIAN
			MAESTRICHTIAN	AJALI	MAESTRICHTIAN
			CAMPANIAN	MAMU	CAMPANIAN
			CAMP/MAESTR	NKPORO SHALE	SANTONIAN
			CONIACIAN/TUR	AWGU SHALE	TURONIAN
			SANTONIAN	EZE AKU SHALE	TURONIAN
			ALBIAN	ASU RIVER GROUP	ALBIAN

1.3.2 Agbada Formation

Deposition of the overlying Agbada Formation, the major petroleum-bearing unit, began in the Eocene and continues into the Recent. The formation consists of paralic siliciclastics over 3700 meters thick and represents the actual deltaic portion of the sequence. The clastics accumulated in delta-front, delta- topset, and fluvio-deltaic environments. In the lower Agbada Formation, shale and sandstone beds were deposited in equal proportions, however, the upper portion is mostly sand with only minor shale interbeds.

1.3.3 Akata Formation

The Akata Formation is located at the base of the Niger delta sequence and consists of prodelta, hemipelagic, and pelagic shales deposited in marine environments. It is composed of thick shale sequences (potential source rock), turbidite sand (potential reservoirs in deep water), and minor amounts of clay and silt. Beginning in the Paleocene and through the Recent, the Akata Formation formed during lowstands when terrestrial organic matter and clays were transported to deep water areas characterized by low energy conditions and oxygen deficiency (Stacher, 1995).

The Niger Delta basin consists of a series of depocenters or belts (Stacher, 1995). Major structure building growth fault determine the location of each depobelt. The entire sedimentary wedge was laid down sequentially in five major depobelt each 30-60km wide, with the oldest lying further inland and the youngest located off shore (figure 3) (Reijers 1996).

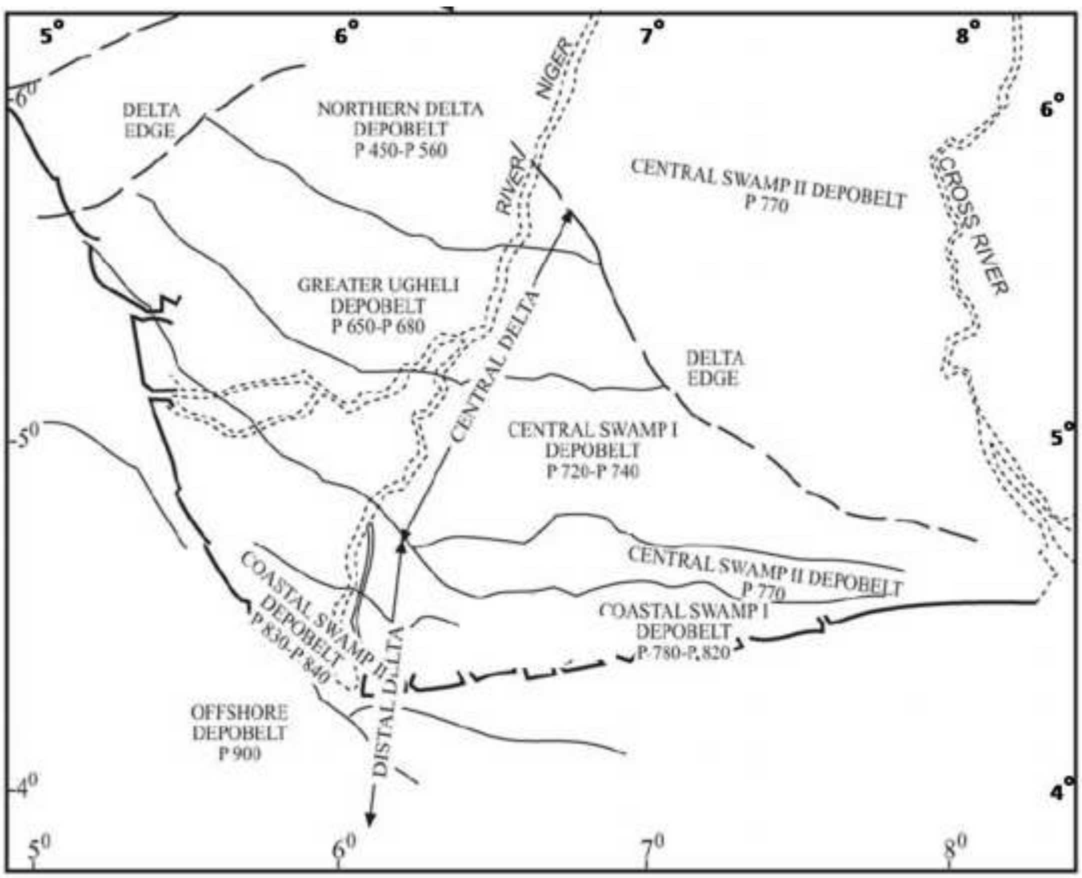


Figure 3: Map of Niger Delta showing the different depobelt (modified after Knox and Omotsola, 1989)

1.4 Structural Setting

Weber and Daukoru, (1975), recognized four main types of oil field structure (figure 4), they are: -

1. Simple rollover structure
2. Structure with multiple growth fault
3. Structure with antithetic fault
4. Collapsed crest structure

These structures are generated by rapid sedimentation and gravitational instability during the accumulation of the Agbada deposits and continental Benin sands over the mobile undercompacted Akata prodelta shale.

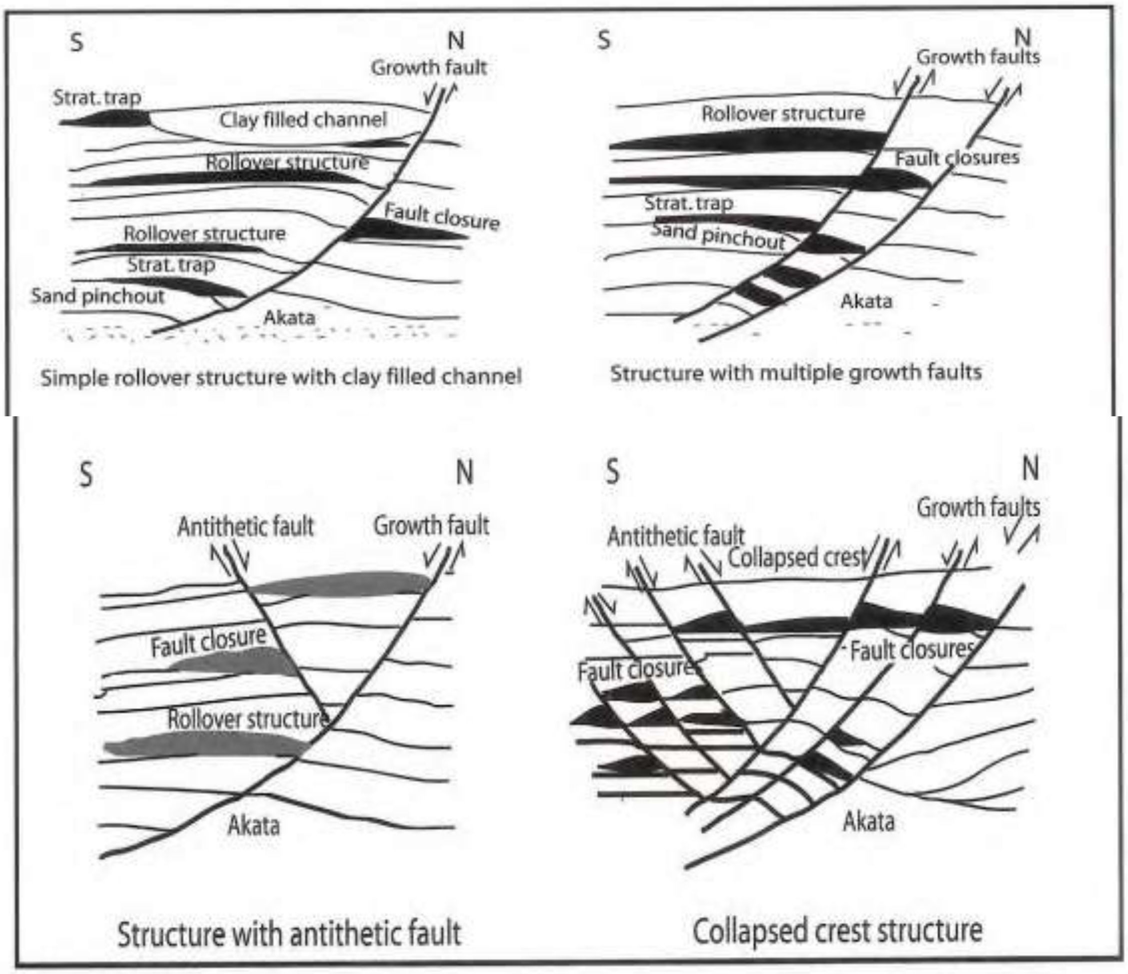


Figure 4: Examples of Niger delta oil field structures and associated trap types (Burke, 1972; Reijers, et al., 1997; Tuttle, et al., 1999).

1.5 MATERIALS AND METHODS OF STUDY

The Data used for this research work was made available by Total Nigeria (TPNG), Port Harcourt.

1.5.1 Materials

The material used in the study includes the following: -

- Base map showing the structural element and location of wells, figure 2.
- Suite of wireline log.
- Set of core photographs.

1.5.2 Methods

Two main methods of study were employed in this research work. They are core description and the use of wireline logs interpretation: -

1.5.2.1 Core Description

The core photographs provided were studied and described from bottom upwards. The procedure for the description is as follows: -

1. The detail description of the core's photos was done on the core sedimentological description chart

2. Texture, litho unit boundaries, nature of contacts, composition, diagenetic features, biogenic and physical sedimentary structures were described and recorded
3. Their lateral and vertical variation of lithology were noted and studied.
4. Study of sedimentary structures was carried out noting features like cross bedding, lamination e.t.c. The degrees of bioturbation were also indicated.
5. Based on the descriptions, lithology and grain size, dominant sedimentary structures, the lithofacies types were determined and interpreted using the lithofacies classification scheme (table 2)

1.5.2.2 Well logs

Interpretation Well logs provided was used to: -

1. Interpretation of various lithofacies within the core was integrated with the wireline log pattern to arrive at lithofacies association and distinct reservoir genetic units.
2. Well log sequence stratigraphy interpretation

Table 2: Tabulated Lithofacies Scheme (After S.P.D.C, Nigeria)

DOMINANT GRAIN SIZE	DOMINANT SEDIMENTARY STRUCTURE	SECONDARY SEDIMENTARY STRUCTURE
S (sandstone) **c** - coarse, **m** - medium, **f** - fine >90% sand **H** (heterolithic) **s** (sandstone dominant) >50% sand / >50% mud **m** (mudstone dominant) >90% mud **M** (mudstone) **C** (coal)	**M** (massive) **X** (cross-bedded) **P** (planar, parallel bedded) **H** (hummocky - swaley cross-bedded) **W** (wave rippled) **C** (current rippled) **B** (bioturbated) **R** (rooted) **F** (fossiliferous) **O** (organic-carbonaceous)	**C** (cement-general) **S** (siderite) **/d** (soft sediment deformed - slumped, slide, micro-faulted)

1.5.2.3 Wireline Log Shapes

The Gamma ray log is an indicator of shale content in a formation, it shows greater detail and are related to the sediment character and depositional environment. It is a log of the natural radioactivity of the formation along the borehole, measured in API particularly useful for distinguishing between sands and shales in a siliclastic environment. A bell-shaped log with gamma ray value increasing upwards to a lower value indicates increasing clay content (Figure 5). A funnel shape with the values decreasing regularly upwards shows a decrease in clay content. The decrease in clay content is correlated to an increase in sand content and grain size. Shapes on the Gamma ray log can be interpreted as grain size trends and by sedimentological association as cycles. A decrease in gamma ray value will indicate and increase in grain size. Fine grain size will correspond to higher gamma ray values. The sedimentological implication of this relationship leads to a direct correlation between facies and log shape.

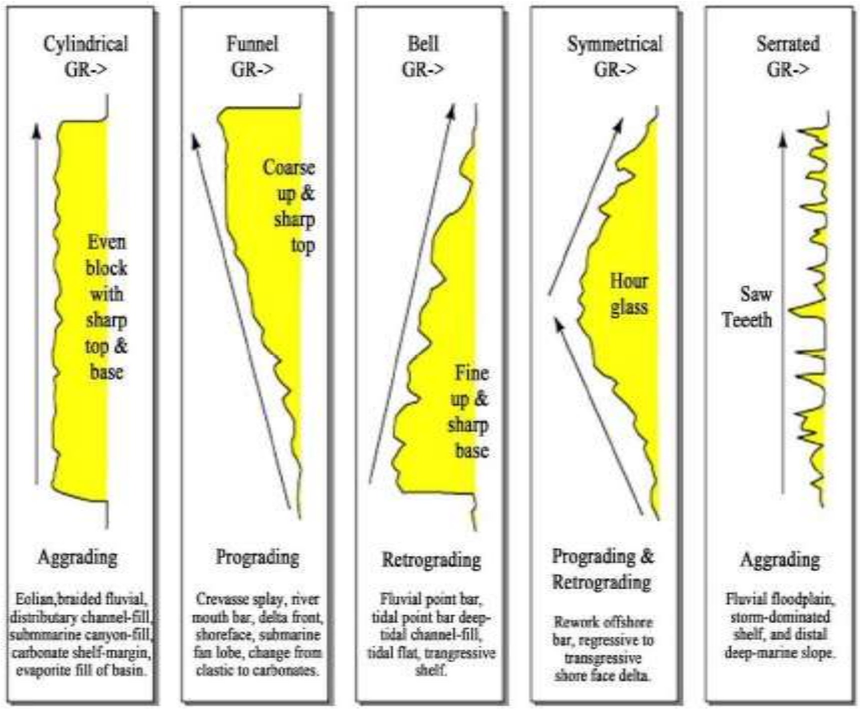
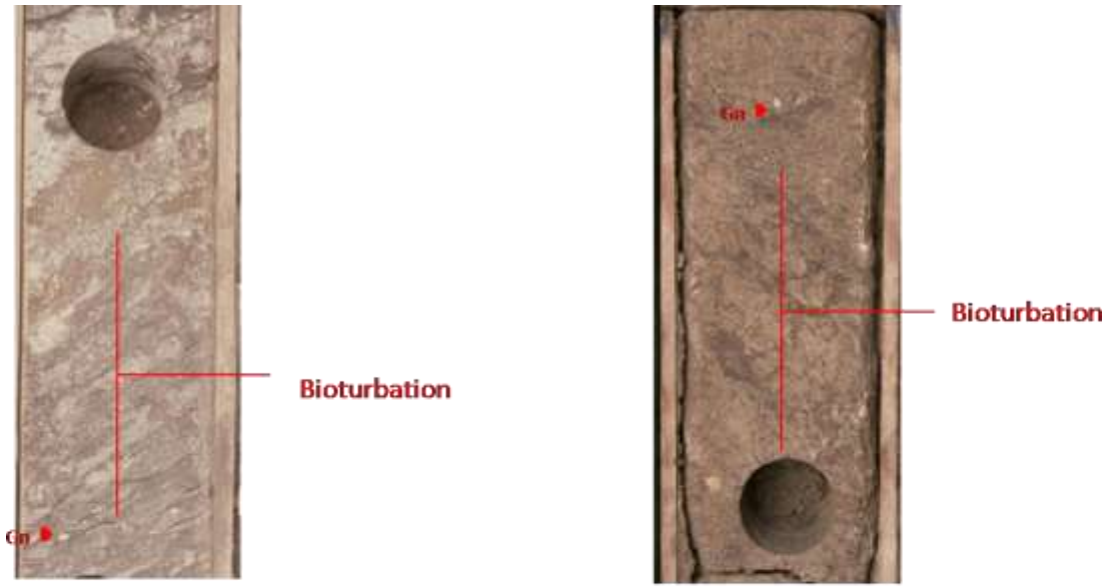


Figure 5: Facies indication from Gamma Ray, the idealized examples of both Log shapes and sedimentological facies (Schlumberger, 1989).

1.6 RESULT AND INTERPRETATION

1.6.1 Lithofacies Analysis Eight lithofacies types were recognized in the "B1" Reservoir Sand, based on lithology and sedimentary structures (Plate 1-8). For each lithofacies identified, facies description and interpretation for the facies is immediately followed. Some of the lithofacies in the study interval occur separately in different positions in the section and may even be repeated (Figure 6).

1.6.1.1 Lithofacies 1: Bioturbated Medium to Coarse grained Sandstone (BmcS) facies occurs twice between (3322-3323m) and (3324-3327.5m) depths. It consists of medium to coarse grained sand, poorly sorted, with bioturbation ranging from moderate to intense (Plate 1a-b). The sandstones contain grain-size of various clast, with sizes ranging from medium to coarse with few granules in places. The physical sedimentary structure is not pronounced as these have been intensively obliterated by the action of bioturbation. But biogenic structure in these facies includes burrows of Ophiomorpha and Skolithos.



a:(3322-3323m), b:(3324-3327.5m),

Plate 1: BmcS ;Gn: granule

Interpretation: The coarse to occasional granule nature of this lithofacies suggests a lag deposit generated by strong ephemeral current as in storm and major flood (Dalrymple et al., 1992). Lack of predefined internal bedding structure indicates rapid sedimentation (Allen, 1983). Intensively bioturbation correspond to a zone where nutrient is abundant. This lithofacies is suggestive of a lag deposit.

1.6.1.2 Lithofacies 2: Cross Bedded Fine to Medium Sandstone (CBfmS) facies occur twice in the study interval, between (3323-3323.5m) and (3332.7-3335.3m) depths, with sharply defined scoured base (Plate 2a&b). The sandstone moderate to well sorted, clean with little or no clay content. Visible sedimentary structures include planar cross bedding. The grain size ranges from fine to medium. Bioturbation in these facies is rare.

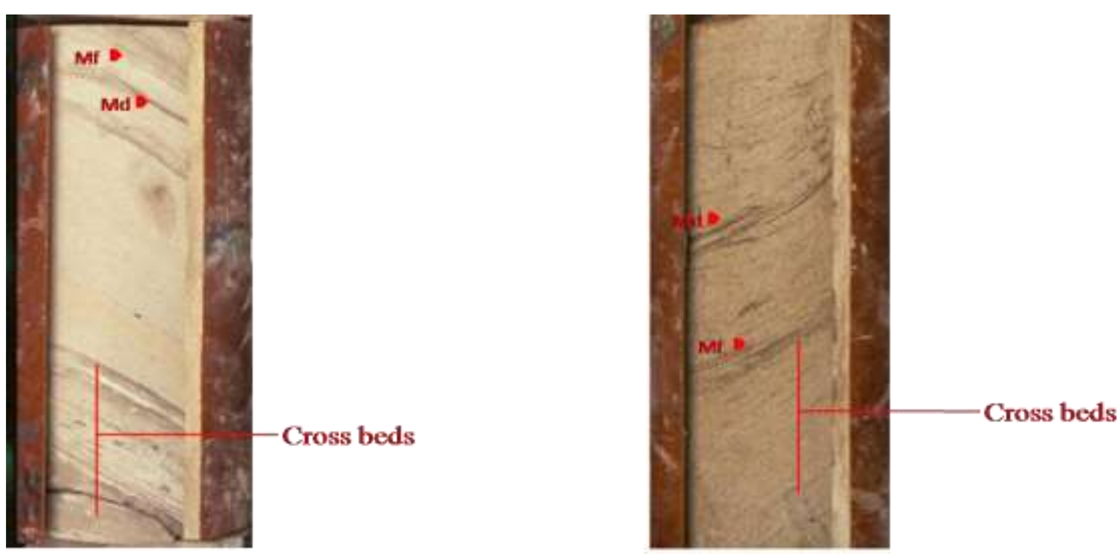


Plate 2: CBfmS (3323-3323.5), Md: mud drape, Mf: mud flase

Interpretation: Grain-size, sorting and planar cross-bedding are typical of proximal deposits under unidirectional current. They are formed under strong upper flow regime condition such as in channels and wave dominated environment (Walker, 1984). The dunes were crescentic with trough shaped scour pits producing trough cross stratification. The well-sorted character of the sediments is typical of marine sourced sands reworked by tidal and wave process. The lithofacies could be interpreted to be deposit of tide-dominated estuarine channels and tidal inlet channels. This section on the Gamma ray log shows bell shape, indicating a finning upward sequence of a fluvial channel.

1.6.1.3 Lithofacies 3: Mudstone (M) facies encountered in the study interval occur twice between the depths of (3323.5-3324m) and (3337-3338.5m). It consists of laminated dark-greenish-gray to greenish-black mudstone (Plate 3a&b) with thin silty laminations. These facies are characterized by thin elongate, diagenetic siderite nodules, and nodular concretions of diagenetic siderite. Physical sedimentary structures present in these facies include planar lamination and oblique planar lamination. Bioturbation in these facies is slight to rare; it is characterized by Paleophycus, burrowing parallel to laminae.

a:(3323.5-3324m) b: (3339.2-3340m)

Plate 3:Mudstone (M); Si: diagenetic siderite, Pl: *Paleophycus* burrow

Interpretation: The sediment of the mudstone facies was probably deposited under quiet and low energy conditions, allowing for shale lamination. The sections with silty laminae are indicative of the intrusion of a more energetic event. Preservation of thin laminations, absence of bioturbation, and dark colour are suggestive of anoxic and reducing bottom-water conditions. Walker and Plint (1992) and Reineck and Singh (1980) described mudstones as offshore or shelf deposits. The mudstone unit with silty laminae is interpreted to have been deposited in an overbank of a channel while the black/dark laminated mudstone is interpreted to have been deposited in a shelf environment.

1.6.1.4 Lithofacies 4: Bioturbated Sandy Heterolithic (BSH) Facies. These facies occur once in the study interval at the depth interval of (3324-3328m). It consists of fine-grained silty sand and muddy sandstone. Sorting in these facies is moderate, with the heterolithic mixture of fine sand, silt and clay. Bioturbation ranges from moderate to intense and physical sedimentary structure in these facies is not pronounced as bioturbation structures predominate over physical structures (Plate 4). The burrows of Ophiomorpha and

Planolites occur in places, all of which cut or disrupt the original bedding or lamination. The bioturbated sandy heterolithic facies directly overlies the medium to coarse grained sandstone facies and underlies the bioturbated medium to coarse grained sandstone facies in the study interval.

Plate 4: BSH (3327-3328.5m) Ss: sandstone, Mu: mud, Op: *Ophiomorpha burrow*

Interpretation: The lithofacies records the alternation of bedload and suspension depositional processes. The bedload sedimentation is deposited during migration of wave ripples under low flow regime oscillatory wave current while the clay and silt deposits are as a result of suspension fallout, periodically interrupted by sand deposition. The localized trace fossil assemblages are indicative of a stressed environment as a result of wave current action. The intense burrow activities are indicative of deposition in a low energy environment of shallow marine or of lower shoreface. This section on the Gamma ray log shows a funnel shape indicating lower shoreface.

1.6.1.5 Lithofacies 5: Medium to Coarse grained sandtone (MCS) Facies. This litofacies MCS consists of medium to coarse grained sandstone (Plate 5a&b). The facies are moderately to poorly sorted and is characterizes by bimodal grain size sorting appearing as alternation of coarser and finer grain strata (Plate 5a). Bioturbation intensity is rare to absent in these facies. Physical sedimentary structure is in this lithofacies are not pronounced except for the massive bedded nature of the facies. This lithofacies occur once between (3328.5-3329.15m) depths in the cored interval.

Interpretation: This facies is interpreted as upper shoreface deposits because of the massive bedded sands nature of the deposits and the gamma ray log signatures shows a funnel and coursing upward sequence.

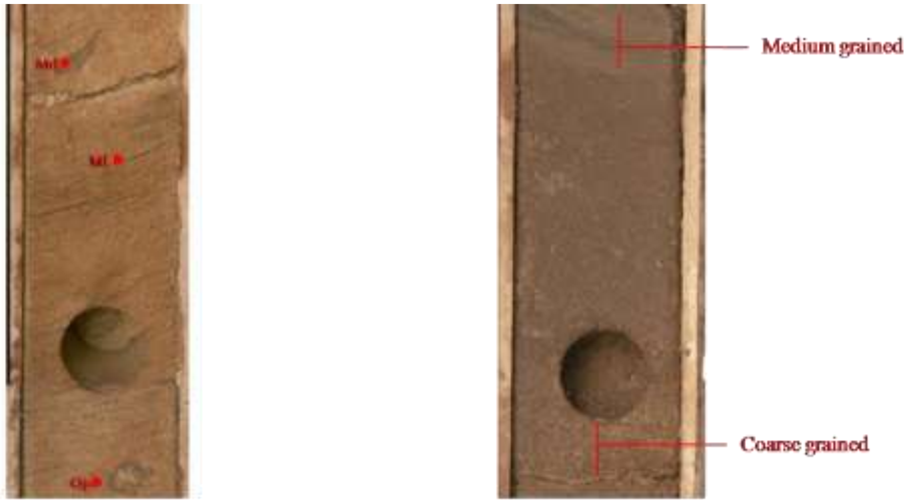


Plate 5: MCS (3328.5-3329.2m); Md: mud drape; Mf: mud flaser, Op: *Ophiomorpha burrow*

1.6.1.6 Lithofacies 6: Cross Bedded Medium- Coarse grained Sandstone (CBmcS) Facies.

The CBmcS consists of moderate to well sorted, medium to coarse grained sandstones (Plate 6a-c). This lithofacies occur within the cored intervals of depth (3329.15-3332.7m). It consists of trough and planar cross bedding (Plate 6a-c), very clean sand with little clay content (Plate 6b). The unit consists of locally trough cross-bedding (Plate 6c). Cross-beds typically contain single and/or paired mudstone drapes along forsets of topsets (Plate 6a&c). The level of bioturbation in these facies ranges from low to moderate bioturbation. Biogenic structure includes Skolithos and Ophiomorpha burrows (Plate 6c).

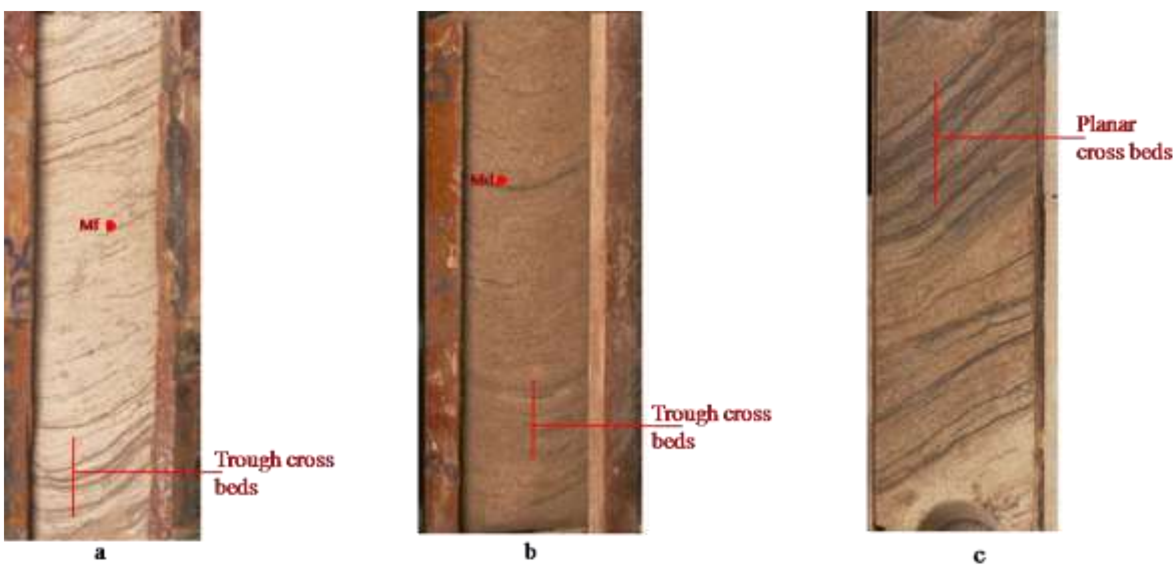


Plate 6: CBmcS (3329.2-3331.5m) and (3331.6-3334.5); Md: mud drap; Mf: mud flaser

Interpretation: Grain-size, sorting and trough cross-bedding are typical of proximal deposits under unidirectional current. They are formed under strong upper flow regime condition such as in channels and wave dominated environment (Walker, 1984). The dunes were crescentic with trough shaped scour pits producing trough cross stratification. The well-sorted character of the sediments is typical of marine sourced sands reworked by tidal and wave process. Presence of clay drapes, mud chips and the bimodal sorting is indicative of tidal current modulation of fluvial current which supply the current. The litofacies are interpreted to be deposit of tide-dominated estuarine channels and tidal inlet channels.

1.6.1.7 Lithofacies 7: Bioturbated Fine to Medium Grained Sandstone (BfmS) Facies. The facies BfmS consists of fine to medium-grained sandstone, with little or no clay content, moderately sorted, with bioturbation ranging from moderately to intensively bioturbated. It occurs within the interval of (3335.7-3337.5) of the study interval (Plate 7). The grain-size indicates a reworking of sediment where the primary sedimentary structures have been intensively obliterated. The common burrows include that of sub-horizontal Planolites and burrows of Ophimorpha.

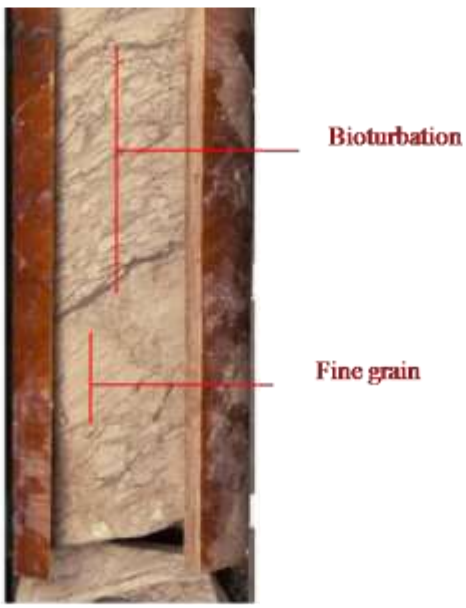


Plate 7: BfmS (3335.7-3337.5m)

Interpretation: Intensively bioturbation correspond to a zone where oxygen content is high, nutrient is abundant and low energy condition, below wave base with dominance of large burrows of Ophiomorpha and Planolites with rare fossil shells, may characterize the influence of tidal or stressed estuarine environment. The intense bioturbation is an indication of lower shoreface. The sorting of the sandstone is probably by tidal currents or by wave action.

1.6.1.8 Lithofacies 8: Bioturbated Muddy Hetrolith (BMH) Facies occurs within the core interval of (3327-3328.5m). It consists of light gray, moderate to intensively bioturbated mudstone, siltstone and relics of very fine sand (Plate 8). Physical sedimentary structures in these facies have not been properly preserved as a result of the bioturbation, and the only evidence of primary sedimentary structure is the presence of relics of planar lamination. The interbedded very fine-grained sandstone and siltstone are heavily bioturbated while the mud intervals are slightly bioturbated. Bioturbation in the facies is dominated by Ophiomorpha and Paleophycus burrows in places; this leads to partial to complete obliteration of the sedimentary structures in some part. The bioturbated muddy heterolith overlies the mudstone facies in the study interval.

Plate 8: BMH (3337.5-3339m)

Interpretation: The lithofacies analysis reveals the interplay of high energy event and fair-weather sedimentation. The high energy depositional phase is recorded by the wavy rippled, finer grained.

Sandstone; the fair-weather depositional phase is characterized by the presence of interbedded, very fine-grained silty sandstones, siltones and mud, which may record the latest stage of sediment fallout after the high energy sedimentation. The heterolithic nature of this facies indicates sedimentation in a setting characterized by alternating suspension fallout and bed-load, while its trace suite indicates deposition in a predominantly low energy setting below wave base. Thus, this deposit is interpreted to have been deposited in the lower shoreface environment.

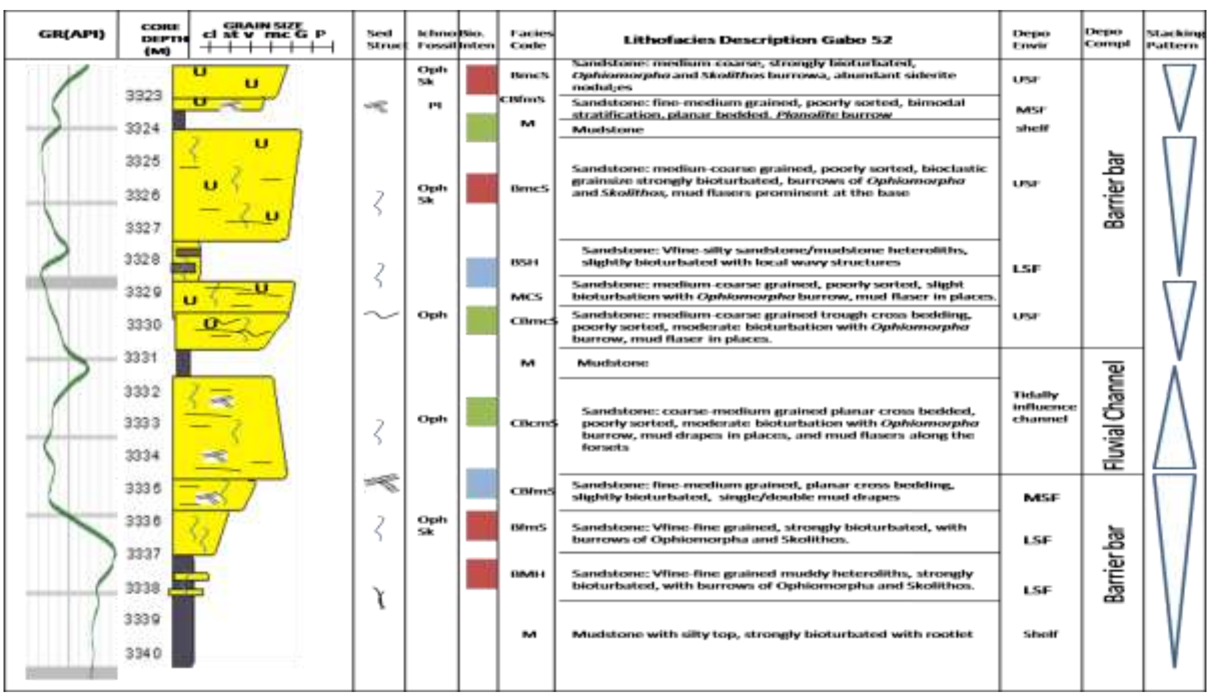


Figure 6: Depositional Sequence for Reservoir "B1" Boga well-16 (3322-3340.5m) showing the various depositional environments and stacking pattern

1.6.2 Facies Association and Interpretation

Facies association according to Reading, (1979) is defined as groups of facies that occur together and are considered to be genetically or environmentally related. It reflects the combination of processes which occur in the depositional environment. These processes include a range of energy level within an environment of deposition. The lithofacies units described above (Plate 1-8) and have been grouped into facies associations which have genetic and environmental significance and can be identified as separate units in cores and on wireline logs (Figure 6). These associations of facies form the primary basis of inferring the depositional setting under which the sediments were deposited and preserved. Two lithfacies association have been identified in the study well. The integrated interpretations of the facies association are hereby presented according to their vertical arrangement in the well starting from the base of the reservoir to the top.

1.6.2.1 Facies Association 1: Barrier Bars

The lithofacies associations 1consists from base to top of mudstone lithofacies (M), bioturbated mudstone heterolith facies (BMH), Bioturbated fine to medium grained sandstone facies and cross bedded fine to medium grain sandstone facies (CBfmS). They are interpreted as that of marine mudstone, lower shoreface, and middle shoreface respectively. The stacking pattern display a vertical coarsening upward sequence and a gradual transition from one lithofacies to another in a prograding shoreface. Figure 7a; shows the vertical facies model for barrier bar profile in the study well. This lithofacies association occurs four (4) times in the studied well with different combinations of lithofacies at various interval of the cored section.

1.6.2.1.1 Shelf Mudstone Subfacies

This subfacies association is made up of successions of the thickly laminated mudstones (figure 7a). The unit is characterized by low levels of bioturbation, except for burrows of Paleophycus in places, and is marked by high GR and low resistivity log response. The mudstone deposits are suspension fall- out deposit which represent low-energy environment such as an open marine self, below storm wave base. This subunit occurs three times in the study well.

1.6.2.1.2 Lower Shoreface Subfaies

This subfacies units overly the mudstone subfacies and it consists of fine grained to medium grained sandstone interspersed with thin layers of siltstone and mud, with an upward increase in sand:shale ratio. The sedimentary structures in this facies include; cross lamination and flaser bedding.The facies is characterized by moderate to intense bioturbation and burrowing of Ophiomorpaha nodosa and Planolites. The association is characterized by gradual coarsening-upward in grain size and is reflected by a funnel-shape of GR log curve repeated serration, indicating alternations of sand and shale as well as upward coarsening and thickening sequence of lower shoreface. This subunit occurs three times in the study well.

Sandstone; the fair-weather depositional phase is characterized by the presence of interbedded, very fine-grained silty sandstones, siltones and mud, which may record the latest stage of sediment fallout after the high energy sedimentation. The heterolithic nature of this facies indicates sedimentation in a setting characterized by alternating suspension fallout and bed-load, while its trace suite indicates deposition in a predominantly low energy setting below wave base. Thus, this deposit is interpreted to have been deposited in the lower shoreface environment.

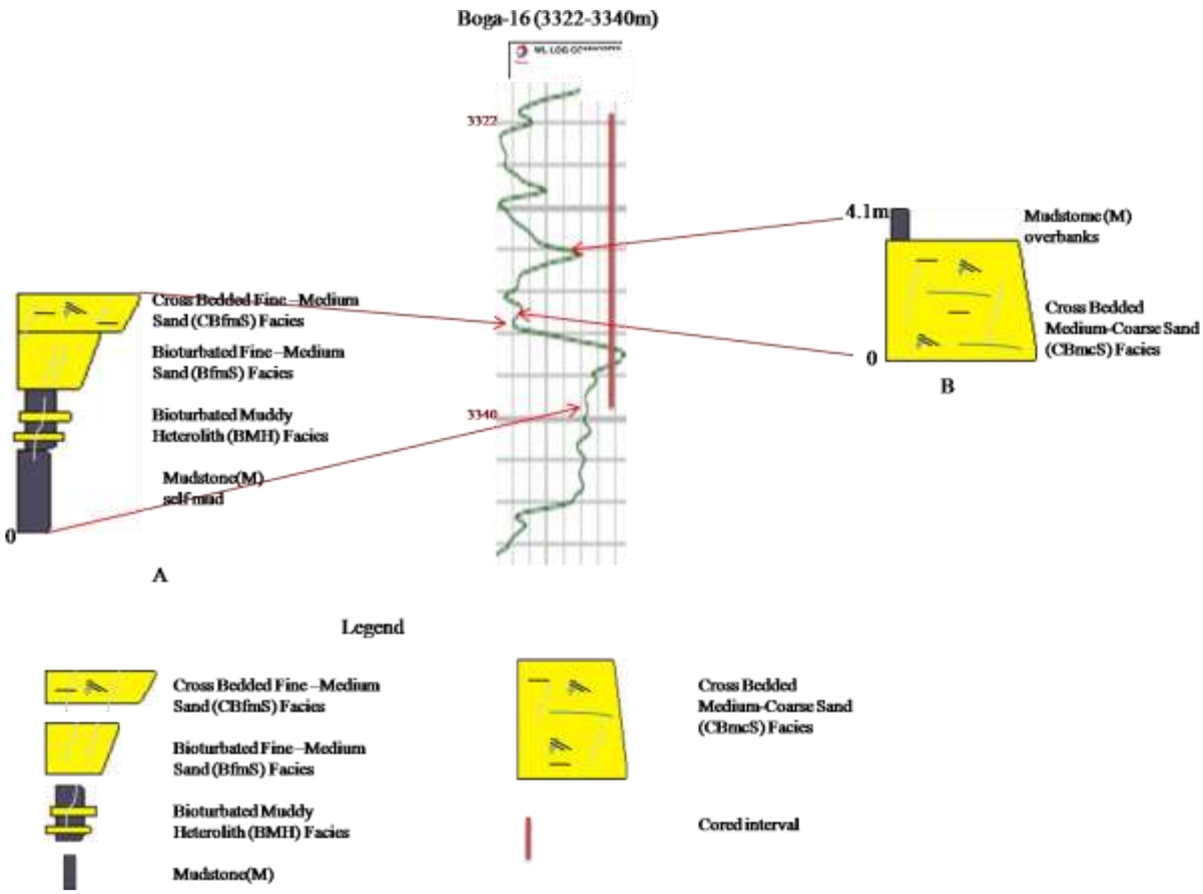


Figure 7: Vertical facies model for a: barrier bar profile and b: Fluvial Point Bar Sequence in the study well

1.6.2.1.3 Middle Shoreface Subfacies

This subfacies unit overly the lower shoreface described above. It is characterized by coarser sand of fine to medium grained sandstone than the lower shoreface deposit described above. Bioturbation in this subfacies is rare and less pronounced than the lower shoreface but more pronounced than the overlying upper shoreface subfacies. Due to strong wave interaction, the sands are well sorted with low shale interlamination than the underlying subfacies. Physical sedimentary structure includes cross stratification and mud drapes, though, planar cross stratification may be locally developed. This subunit occurs twice in the study well.

1.6.2.1.4 Upper Shoreface Subfacies

This subfacies units is characterizes by a coarsening-upward, shale-free sandstone with thickness ranging between 1 and 4m in the study wells and it occur three time in the study well. They are clean and well sorted medium to coarse-grained sandstones. This subfacies contain little or no mud which reflects constant agitation of waves and currents that do not allow mud to settle out from suspension. Physical sedimentary structure includes planar and cross bedding with both trough cross-beds. Burrows of high energy environment such as Ophiomorpha and Skolithos (McEachern and Pemberton, 2003) characterized this unit. This facies association has a funnel shape GR log signature, which reflects the coarsening-upward sequence of the upper shoreface deposit.

1.6.2.2 Facies Association 2 (Fluvial Channels-Point Bar)

The facies association is characterized by a fining upward sequence, consisting of fining upward coarse to medium sand (CBcmS), that are poorly sorted and is capped by mudstone (M) lithofacies of an over bank deposit. The basal contact is usually sharp and may be lagged by coarser sand, gravels and pebbles. The dominant physical sedimentary structures are the planar cross bedding. Bioturbation is rare to slight and are dominated by Ophiomorpha burrows. The poorly sorted nature and coarse grain size of the sandstone reflect a fluvial dominated character as migrated by high energy fluvial currents.

Allen, 1990, defined point bar deposits as a meandering river deposit with sequence consisting of in-channel deposits (Lateral accretion) followed by over bank (vertical accretion). The facies association is characterized by a fining upward bell-shaped GR log signature. It occurs once in the in the study well. (Figure 7b) is the vertical facies model for fluvial channel point bar profile in the study well.

1.6.3 Depositional Model for the “B1” Reservoir Sandbodies

The facies association of the cored intervals in the “B1” reservoir sandbodies can be interpreted as a deposit of a prograding wave-dominated shoreface setting (figure 6). This observation is implied from the lithofacies association (figure 6), the shoreface is not well developed; it encompasses association of two of three main domains at various dept interval. The upper shoreface is located landward, above the limit of tide influence; followed by the middle shoreface; the lower shoreface is submitted to seasonal tide action and water table infringing, it is a wetter environment.

Wave processes are more dominant than the fluvial processes as seen in the cored section (figure 6). This interpretation is supported by the abundance, both in thickness and frequency of shoreface deposits encountered on cored intervals and by the facies of the shoreface themselves, with the exception for the fluvial process that incised and deposited the Point Bar deposit between the cored interval (3331.5 – 3334.6m), corresponding to a weak winnowing by the wave action, and very few swaley cross-stratifications indicating high reworking by wave action.

1.6.4 Well Log Sequence Stratigraphy

Three types of systems tracts are identified from the available well log in the cored interval. These are Lowstand Systems Tracts (LST), Highstand Systems Tracts (HST) and Transgressive Systems Tracts (TST). Each systems tract is deposited at a predictable position in an interpreted base level cycle caused by eustasy, and has recognizable signatures and stacking pattern in well logs (Mitchum et al, 1977).

The Lowstand Systems Tract (LST) consists of the oldest deposit within a depositional sequence and is bounded at the base by a sequence boundary (figure 8). It consists of basin floor fan (BFF), slope fan (SF), and prograding wedge complex (PWC). The basin floor fan is characterized on gamma ray and resistivity logs by blocky pattern with relatively few breaks thus indicating massive sand body. The slope fan shows typical sand – poor facies with overall rounded shape of spiky sand package on gamma ray log. The prograding wedge complex which is the uppermost unit of the Lowstand Systems Tract is characterized by an overall coarsening upward (i.e., Inverted christmass tree) pattern on gamma ray log. This is interpreted as a gradual overall shallowing upward pattern from marine to non-marine environments.

The Highstand Systems Tract (HST) consists of younger strata within a depositional sequence and is widespread on the shelf. It is bounded at its base by maximum flooding surface and at the top by sequence boundary. Highstand systems tract begins with coarsening upward pattern which is predominantly forestepping basinward. It is characterized by relatively decreasing resistivity readings. The Transgressive System Tract (TST) is the middle systems tract in an ideal depositional sequence and develops as a result of an increase in the rate of sea level rise. Condense section which is thin marine facies consisting of pelagic to hemipelagic sediments occurs within transgressive systems tract and represents a time of detrital sediment starvation in the depositional basin. The transgressive systems tract is characterized by a relatively increasing gamma ray and decreasing resistivity readings, marked by fining upward pattern that persists vertically until the maximum flooding surface is reached. The transgressive systems tract is bounded at its base by transgressive surface while maximum flooding surface is characterized by lowest resistivity and highest gamma ray readings.

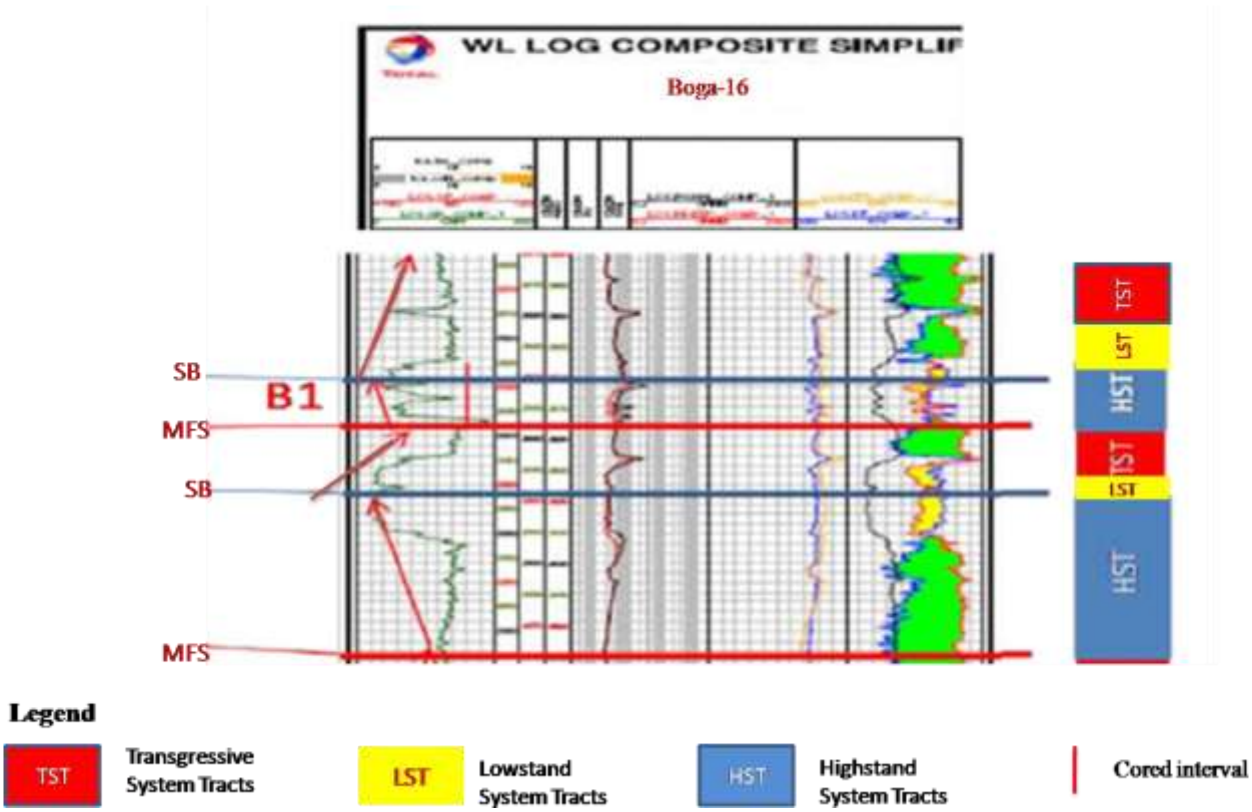


Figure 8: Reservoir "B1" Boga 16 Stacking Pattern and Sequence Stratigraphic Frame work

1.6.4.1 INTERPRETATION AND DISCUSSION

One sequence has been recognized in this cored interval (Figure 8).

Sequence I (3322 – 3340 m). In this sequence, the lowstand systems tract was not cored. The Transgressive Systems Tract (TST: 3338 - 3340 m) is made up of retrogradational stacking pattern of interbedded clay, shale, mudstone, and silty mudstone single unit of about 2 m thick of Bioturbated Muddy Heterolithic Facies (BMH) at 3337.5 m. The Transgressive Systems Tract thinned into a major condensed section MFS, indicated by the High GR reading and low resistivity reading. The Highstand Systems Tract (HST) 3329 – 3338 m) is made up of shale/mudstone prograding to argillaceous siltstone that changed to aggradational unit of sandy mudstone interbedded by thinly bedded medium to coarse grained sandstone of about 8 m thickness. The Highstand Systems Tract is terminated at the top by sequence boundary at 3329 m depth, which is defined at the point of inflection in the stacking pattern from net coarsening upwards to net fining upwards. The noticed abrupt change in the gamma ray log signature indicated an erosional truncation that defined the aforementioned sequence boundary.

1.7 CONCLUSION

A detail sedimentological study of "B1" reservoir sand body, containing 18.5m cored samples were integrated with analysis of wire line logs to determine the various lithofacies, in order to understand the depositional environments responsible for the deposition of the reservoir sands in the Well-16, Boga field. Eight lithofacies were identified and base on the facies association, two depositional environments were identified. The depositional environment includes the shoreface deposits of the barrier bars and fluvial channel point bar deposit.

The shoreface succession in the study interval is not well developed; it encompasses association of two of three main domains at various depth intervals. The upper shoreface is located landward, above the limit of tide influence; followed by the middle shoreface; the lower shoreface.

The point bar sequence was encountered in this studied cored interval of (3331.5 – 3334.6m), depth and was identified in the wire line log and is characterized by a fining upward sequence of cross bedded medium to coarse grained facies (CBmcS) and is capped by overbank sediment of mudstone facies (M). The log profile of point bar in this study is similar to that proposed by Galloway and Hobday (1996). It is characterized by a bell shape, which reflects a general fining upward sequence.

These features correspond to decrease in grain size and increase in interstitial clay upward. The facies association of the cored intervals "B1" reservoir sandbodies can be interpreted as a deposit of a prograding wave-dominated shoreface setting. This observation is implied from the lithofacies association (figure 6), and is supported by the abundance, both in thickness and frequency of shoreface deposits encountered on cored intervals and by the facies of the shoreface themselves, with the exception of the fluvial process that incised and deposited the Point Bar deposit between the cored interval (3331.5 – 3334.6m), corresponding to a weak winnowing by the wave action, and very few swaley cross-stratifications indicating high reworking by wave action.

One sequence has been recognized in this cored interval, Sequence I (3322 – 3340 m). In this sequence, the lowstand systems tract was not cored.

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